Mechanical Testing in Pressurized Hydrogen and Carbon Dioxide

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Abstract. This document presents an overview of mechanical tests realised in pressurized hydrogen, carbon dioxide and nitrogen on an experimental platform developed in Pprime Institute. The objective is to highlight the specificities of these experiments and of the associated instrumentations.

Introduction

The forthcoming shortage of fossil energy sources and environmental concerns motivate the diversification of energy sources. Hydrogen, due to its high energy potential can be used in many applications without releasing greenhouse gases. Otherwise, the actual plant coal production stations need to evolve by treating the releasing greenhouse gases inherent to this manufacturing. Therefore, on one hand, the integrity of the hydrogen transport and storage structures cannot be guaranteed without understanding the damage mechanisms in such an environment which is well known to decay material proprieties. On the other hand, to plan the carbon dioxide storing and its transport under high pressure, we need to control of the durability of materials in such penetrating gas environments. With those goals, a test rig, named HYCOMAT, has been designed and developed in order to study the mechanical behaviour of materials at medium and high pressures of gaseous hydrogen, carbon dioxide and nitrogen.

HYCOMAT: a Mechanical Test Rig under Gas Pressure

Principle. The principle of the test rig is to associate a cell under gas pressure with a servo-hydraulic machine which applies the loading on a specimen (as shown on Fig. 1 and Fig 2). An automatic regulation of pressure and temperature with PID control insures the gas management. Besides the flammability and explosiveness of hydrogen are the most important risks to take into account to guarantee the security of investigators and of the surrounding area.

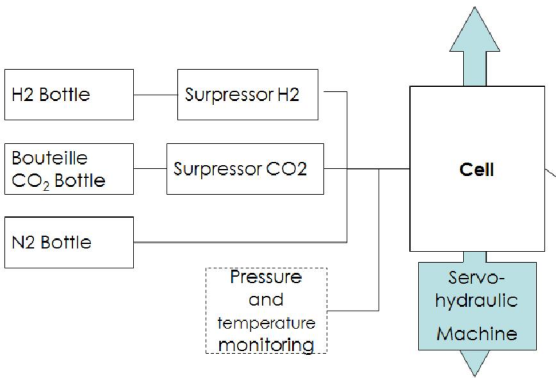

Figure 1: Schematic overview of test rig under pressurized hydrogen, carbon dioxide, nitrogen

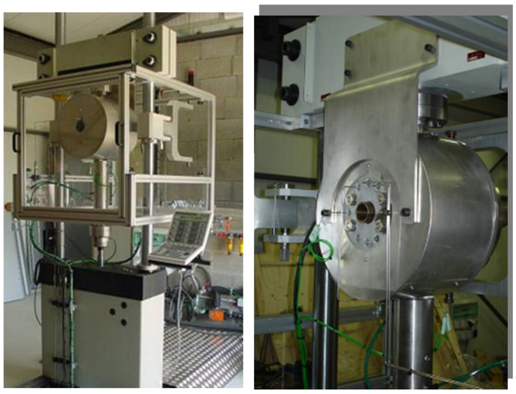

Figure 2: Front and back of the HYOCOMAT test rig for mechanical testing under pressurized gas (H2, CO2 and N2)

Technical specifications. The specifications of the HYCOMAT test rig are summarized in Table 1. For hydrogen and nitrogen, a compression rate of 30bar/min and a decompression rate of 10MPa/min can be reached. The main specificity of the test rig resides in the use of an internal pressure-compensated load cell to monitor the applied load without any friction force on the lower rod. Moreover, two different front doors permit optical observations and measurements: one with a 40 mm (15,7 in) diameter porthole which can operate up to 40 bars and one with a 26 mm (10,2 in) diameter porthole (up to 400bar). In addition a 26 mm rear porthole at 26 mm (10,2 in) (up to 400 bar) can be used for lighting and/or transmission of optical signals (Fig. 2).

Gas nature	H2, CO2, N2
Pressure [bar]	400
Temperature [°C] ([°F])	150 (302)
Load cell in tension [kN]	25
Actuator displacement [mm] ([in])	20 (7.9)

Table 1: Principal capabilities of HYCOMAT

Overview of Mechanical Tests in Pressurized Gas and their Specific Instrumentations

Static and monotonic tests. To study the hydrogen influence on some key mechanical properties, sustained–load experiments tests for example on flat dumbbell polymer specimens (Fig. 3) can be performed on this equipment [1]. For strain measurement, a markers tracking method has been developed using Python code.

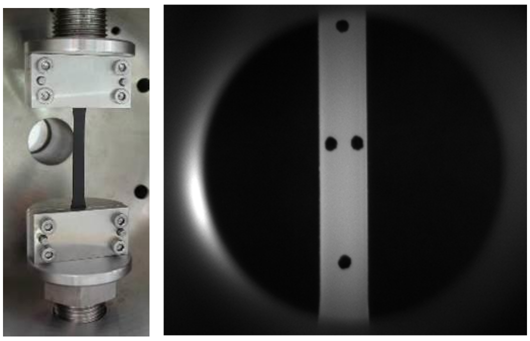

Figure 3: Flat dumbbell polymer specimen and strain measurement by patterning

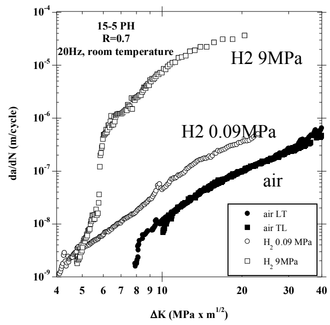

Figure 4: da/dN vs ΔK curves obtained under two hydrogen pressures 0.09 and 9 MPa, compared to the one obtained in ambient air.

Fatigue. Fatigue crack growth tests are carried out under different pressure of hydrogen. Different metrology techniques are used: DCPD, optical crack length monitoring by means of a Questar long-distance microscope, back-face strain gages for crack closure measurements. As an example, the crack propagation curves shown in Fig. 4 in the case of a martensitic stainless steel indicate a pronounced fatigue crack growth enhancement. This enhancement depends on hydrogen pressure and loading frequency. Meanwhile typical changes in fracture modes are observed [2].

Cavitation. Elastomers are also tested under pressure, particularly for the study the cavitation mechanisms in these materials [3]. In these tests use the visual access to specimen surface through the portholes is essential to characterize the formation of cavities in the gas decompression by using image treatment and analysis.

Dilatation. Experiments of elastomer dilatation under hydrogen and carbon dioxide pressure are leaded to calculate material properties to feed coupled thermal-diffusion-mechanical numerical models. Observations are performed at different scales using standard lens for markers tracking method and Questar long distance microscope as shown on Fig. 6 for smallest strain measurement.

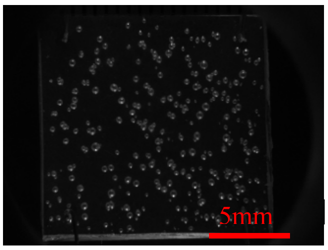

Figure 5: Example of cavitation in an elastomer during decompression of hydrogen pressure

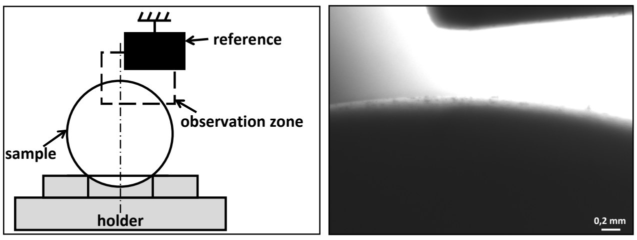

Figure 6: Measurement of dilatation of a spherical specimen in an elastomer under hydrogen pressure

Conclusion

The results of these experiments on the mechanical response of materials in pressurized gas are needed to improve the current knowledge on material compatibility, in particular with respect to complex issues related coupled thermal-diffusion-mechanical processes. However, many technical problems have to be taken into consideration. Progress in understanding environmental effects requires the introduction of additional metrology techniques. Thus, a hygrometer has recently been mounted on the cell. Finally, the increasing demand of studies in this thematic field has led to development of an additional test rig that will be operative in the next months.

References.

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